GNSS orbit validation using SLR observations at CODE

IGSWS2016
International GNSS Service
Workshop 2016
8 - 12 February, 2016
Sydney, Australia

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Introduction

Satellite Laser Ranging (SLR) provides a powerful tool to validate satellite orbits of Global Navigation Satellite Systems (GNSS) that are solely computed from microwave data. So far, only two GPS satellites are equipped with laser retroreflectors. In contrast, all GLONASS, Galileo, BeiDou, and QZSS spacecraft can be tracked via SLR. The Center for Orbit Determination in Europe (CODE) is an Associate Analysis Center of the International Laser Ranging Service (ILRS). Since 2004 CODE has been computing the SLR residuals with respect to CODE's 3-day rapid orbits (i.e., GPS and GLONASS orbits) on a daily basis.

Principle of SLR validation

The principle of validating GNSS orbits using SLR is simple: the SLR observations ('observed') are directly compared against the geometry based on the coordinates of the SLR stations and the microwave-based orbit ('computed') without estimating any parameter. The residuals ('observed minus computed') indicate how well the orbits agree with the SLR observations. Note that since the maximum angle of incidence of a laser pulse to a GNSS satellite does not exceed 14°, SLR data are mainly sensitive to the radial component of microwave-based GNSS orbits.

Validation of GLONASS orbits

GLONASS satellites are equipped with laser retroreflector arrays (LRAs) of different types. Whereas the shape of old satellites' LRAs was irregular planar (SVN 779, 791) or a hollow greek cross (SVN 789, 790), all LRAs of the GLONASS-M fleet have a rectangular shape. Those of the new GLONASS-K satellites form a ring (cf. Figure 1 and Table 1). The SLR residuals (cf. Table 1) were computed w.r.t. 1-day (F1) and 3-day orbits (F3), which result both from a reprocessing campaign at the Astronomical Institute of the University of Bern in the framework of the EGSIEM project (see poster by Sušnik et al.). Mean value ν and standard deviation σ are typically smaller for the 3-day orbits, which are more consistent at day boundaries. Averaged over all satellites, ν and σ are -9.7 mm and 38.4 mm for the 1-day orbits and -8 mm and 34.7 mm for the 3-day orbits. The standard deviation decreases from 50.1 mm for the old satellites to 33.5 mm for the M-fleet.

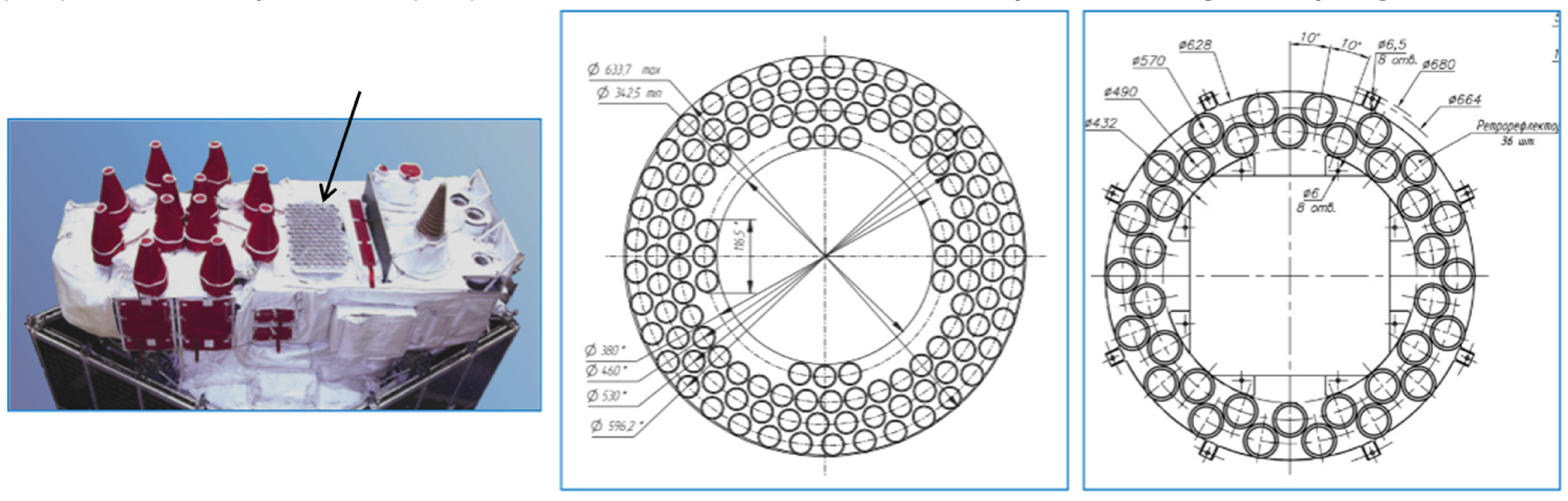

Figure 1: LRAs onboard GLONASS-M (left), GLONASS-K1 (middle), and GLONASS-K2 (right)[a].

Table 1: List of GLONASS satellites with mean value ν (in mm) and standard deviation σ (in mm) of the SLR residuals w.r.t. 1-day (F1) and 3-day (F3) orbits resulting from the ongoing reprocessing campaign at CODE – Repro15 (time span: Jan 2006 to Dec 2012). ν and σ are computed from all residuals whose absolute values are smaller than 200 mm. Residuals having an absolute beta angle smaller than 15° were not taken into account (eclipses).

Type	ILRS Num.	SVN	Slot	COSPAR ID	Launch	Num. of obs.	ν_{F1}	ν_{F3}	σ_{F1}	σ_{F3}
-	87	789	R03	2001-053B	2001	11717	-16.2	-16.0	65.9	50.1
-	89	791	R22	2002-060A	2002	8980	-9.5	0.3	68.9	50.1
M	95	712	R08	2004-053B	2004	20172	-5.6	-6.3	55.6	41.8
M	99	713	R24	2005-050B	2005	18400	-12.1	-13.7	54.4	49.0
M	100	714	R18	2005-050A	2005	1581	9.6	14.5	72.6	72.8
M	101	715	R14	2006-062C	2006	3428	-17.5	-15.9	34.4	32.7
M	102	716	R15	2006-062A	2006	43469	6.9	8.2	40.5	36.9
M	103	717	R10	2006-062B	2006	3554	6.0	5.9	36.7	35.4
M	105	719	R20	2007-052B	2007	3401	-6.4	-4.2	33.2	28.9
M	106	720	R19	2007-052A	2007	3424	-2.3	-1.2	22.1	18.9
M	107	721	R13	2007-065A	2007	3591	-18.6	-18.3	28.6	27.8
M	109	723	R11	2007-065C	2007	34269	-44.6	-43.8	68.2	68.1
M	110	724	R18	2008-046A	2008	14030	-8.7	-9.0	31.9	30.0
M	111	725	R21	2008-046B	2008	2539	-17.1	-15.5	54.2	54.2
M	113	728	R03	2008-067A	2008	3944	-29.8	-29.8	32.1	29.6
M	115	729	R08	2008-067B	2008	38189	-19.6	-19.8	30.7	28.7
M	116	730	R01	2009-070A	2009	3452	-4.2	-3.2	42.8	39.9
M	117	733	R06	2009-070B	2009	2764	-4.0	-6.0	25.5	23.8
M	118	734	R05	2009-070C	2009	15252	-7.2	-7.5	34.3	33.1
M	119	731	R22	2010-007A	2010	2552	-11.8	-10.6	31.3	29.4
M	120	732	R23	2010-007C	2010	11096	-6.5	-6.0	29.5	27.6
M	121	735	R24	2010-007B	2010	3280	-6.1	-3.4	29.4	25.4
M	122	736	R09	2010-041C	2010	5329	-9.6	-8.8	25.8	24.3
M	123	737	R12	2010-041B	2010	5860	-13.7	-12.1	28.2	26.5
M	124	738	R16	2010-041A	2010	5227	-11.4	-9.4	35.2	34.1
K	125	801	R26	2011-009A	2011	2986	-8.2	-9.7	45.2	39.5
M	126	742	R04	2011-055A	2011	4108	-1.4	-2.0	22.5	19.4
M	127	743	R05	2011-065C	2011	780	-8.3	-9.3	30.3	24.9
M	128	744	R03	2011-065A	2011	4186	-4.7	-5.3	24.2	22.0
M	129	745	R07	2011-065B	2011	4447	-10.3	-9.5	31.1	28.6
M	130	746	R17	2011-071A	2011	9199	-7.4	-6.9	25.8	23.5

[a]retrieved from http://ilrs.gsfc.nasa.gov/docs/2014/glonassretros_shargorodsky_20140501.pdf

Table 2: Elevation-dependent center of mass (CoM) corrections for SVN 801[a].

Elevation [deg]	10	20	30	40	50	60	70	80	90
CoM [mm]	1427	1431	1438	1446	1454	1461	1468	1472	1473

For the K-type satellite SVN 801, an elevation-dependent center of mass (CoM) correction is provided (cf. Table 2). For the moment, however, a CoM correction of 1470 mm is applied within the Bernese Software for all elevation angles; this correction is optimal for elevation angles between 70° and 80° (cf. Table 2). Figure 2 shows that (1) the residuals are indeed smallest for elevation angles around 80° and that (2) the residuals approximately follow the elevation-dependent CoM corrections.

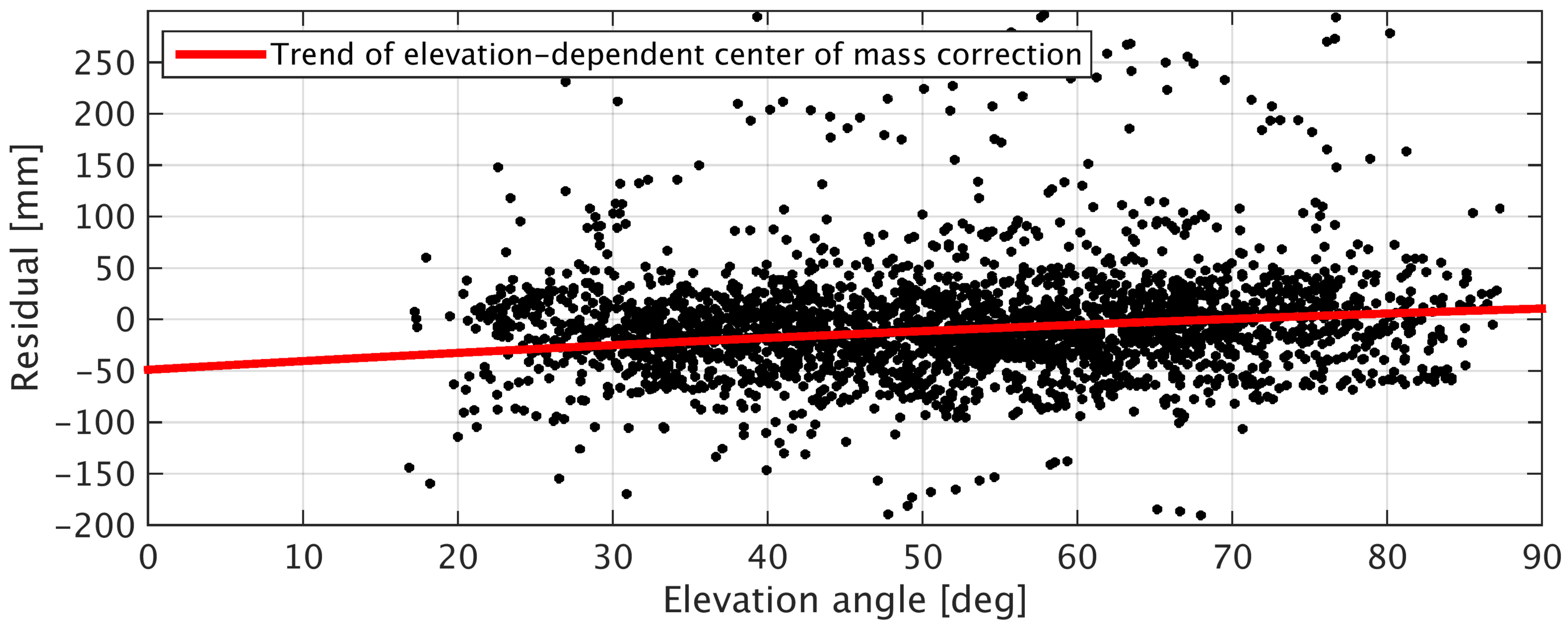

Figure 2: SLR residuals of SVN 801 (new K-type satellite) w.r.t. the reprocessed 1-day orbits at CODE between 2011 and 2014. The red line represents the polynomial fit (2[nd] degree) to the elevation-dependent CoM corrections (cf. Table 2) shifted to the level of residuals for visualization purposes.

[a]retrieved from http://ilrs.gsfc.nasa.gov/docs/glonass125_com.pdf

Validation of GPS orbits

Up to this date only two GPS satellites are equipped with laser retroreflectors. The standard deviation of the SLR residuals w.r.t. GPS orbits is significantly smaller for 3-day orbits (F3), see Table 3.

Table 3: List of GPS satellites with mean value ν (in mm) and standard deviation σ (in mm) of the SLR residuals w.r.t. 1-day (F1) and 3-day (F3) orbits resulting from the ongoing reprocessing campaign at CODE – Repro15 (time span: Jan 2006 to Dec 2012). ν and σ are computed from all residuals whose absolute values are smaller than 200 mm. Residuals having an absolute beta angle smaller than 5° were not taken into account (eclipses).

SVN	Slot	COSPAR ID	Launch	Num. of obs.	ν_{F1}	ν_{F3}	σ_{F1}	σ_{F3}
35	3	1993-054A	1993	14746	-3.8	-2.5	31.1	29.3
36	3	1994-016A	1994	24449	-6.3	-7.3	28.2	27.4

Validation of MGEX orbits

Figure 3 shows the SLR residuals for Galileo, BeiDou, and QZSS satellites, which were computed w.r.t. CODE MGEX orbits. The larger residuals for BeiDou and QZSS occur when the attitude mode is switched from yaw-steering to orbit-normal. No significant differences in the SLR residuals for Galileo IOV/FOC and for BeiDou IGSO/MEO have been detected so far. More details of MGEX are given in the talk by L. Prange (Orbit Modelling Session).

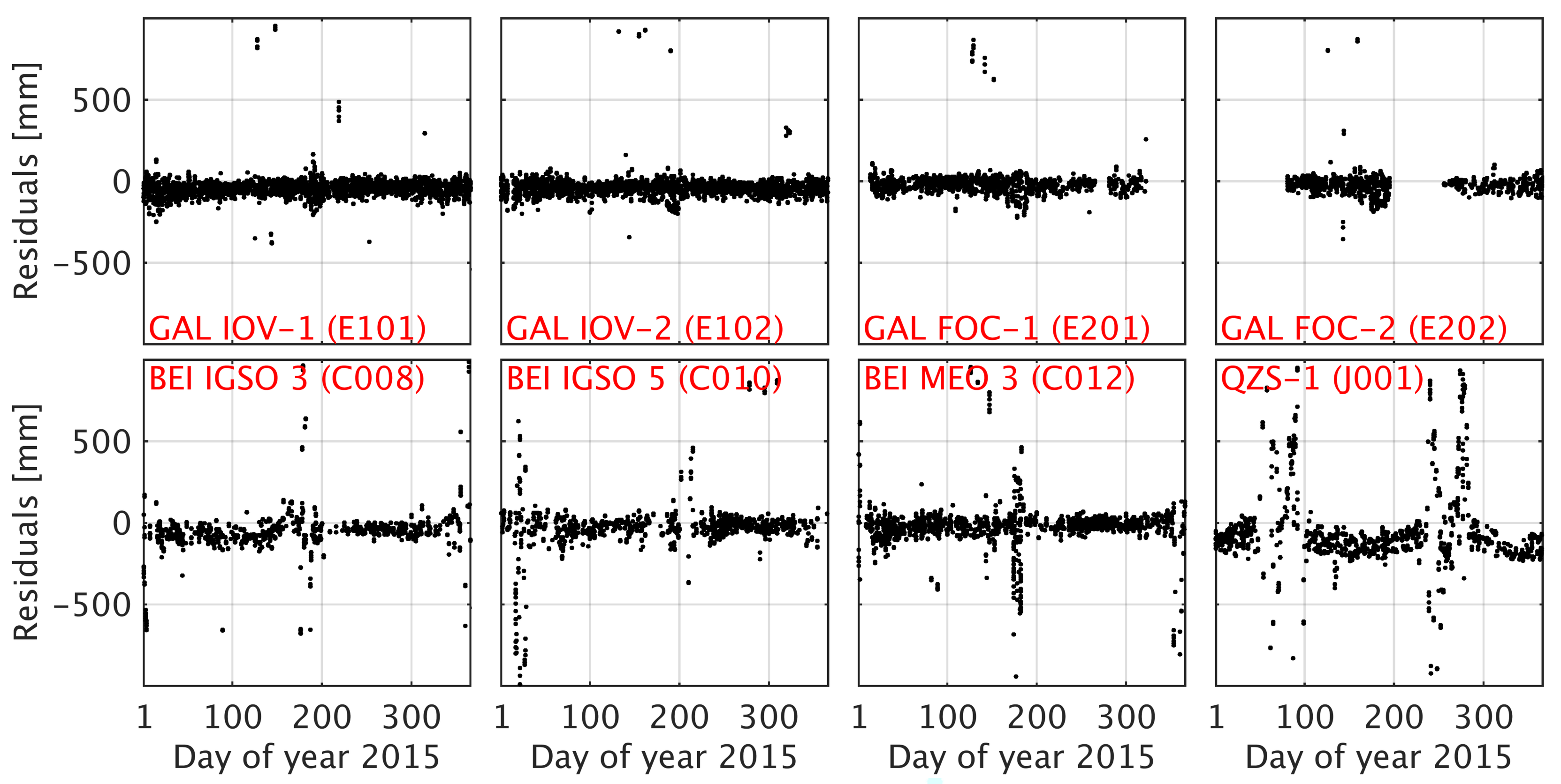

Figure 3: SLR residuals w.r.t. Galileo, BeiDou, and QZSS orbits for the year 2015.

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Poster compiled by A. Maier, February 2016
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